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Ballistic Tests of Used Soft Body Armor

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Bureau of Standards
Engineering Laboratory
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FOREWORD

The Law Enforcement Standards Laboratory (LESL) of the National Bureau of Standards (NBS) furnishes technical support to the National Institute of Justice (NIJ) program to strengthen law enforcement and criminal justice in the United States. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

LESL is: (1) Subjecting existing equipment to laboratory testing and evaluation and (2) conducting research leading to the development of several series of documents, including national voluntary equipment standards, user guides and technical reports.

This document presents the results of a joint NIJ and National Research Council (NRC) of Canada effort to evaluate the effect of age upon the ballistic-resistant capabilities of police body armor. The testing program was administered by the NIJ Technology Assessment Program Information Center assisted by LESL in support of NRC and NIJ.

Technical comments and suggestions concerning this document are invited from all interested parties. They may be addressed to the author or to the Law Enforcement Standards Laboratory, National Bureau of Standards, Gaithersburg, MD 20899.

Lawrence K. Eliason, Chief
Law Enforcement Standards Laboratory

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COMMONLY USED SYMBOLS AND ABBREVIATIONS

A	ampere	H	henry	nm	nanometer
ac	alternating current	h	hour	No.	number
AM	amplitude modulation	hf	high frequency	o.d.	outside diameter
cd	candela	Hz	hertz (c/s)	Ω	ohm
cm	centimeter	i.d.	inside diameter	p.	page
CP	chemically pure	in	inch	Pa	pascal
c/s	cycle per second	ir	infrared	pe	probable error
d	day	J	joule	pp.	pages
dB	decibel	L	lambert	ppm	part per million
dc	direct current	L	liter	qt	quart
°C	degree Celsius	lb	pound	rad	radian
°F	degree Fahrenheit	lbf	pound-force	rf	radio frequency
diam	diameter	lbf·in	pound-force inch	rh	relative humidity
emf	electromotive force	lm	lumen	s	second
eq	equation	ln	logarithm (natural)	SD	standard deviation
F	farad	log	logarithm (common)	sec.	section
fc	footcandle	*M*	molar	SWR	standing wave radio
fig.	figure	m	meter	uhf	ultrahigh frequency
FM	frequency modulation	min	minute	uv	ultraviolet
ft	foot	mm	millimeter	V	volt
ft/s	foot per second	mph	mile per hour	vhf	very high frequency
g	acceleration	m/s	meter per second	W	watt
g	gram	N	newton	λ	wavelength
gr	grain	N·m	newton meter	wt	weight

area = unit^2 (e.g., ft^2, in^2, etc.); volume = unit^3 (e.g., ft^3, m^3, etc.)

PREFIXES

d	deci (10^{-1})	da	deka (10)
c	centi (10^{-2})	h	hecto (10^2)
m	milli (10^{-3})	k	kilo (10^3)
μ	micro (10^{-6})	M	mega (10^6)
n	nano (10^{-9})	G	giga (10^9)
p	pico (10^{-12})	T	tera (10^{12})

COMMON CONVERSIONS
(See ASTM E380)

ft/s × 0.3048000 = m/s
ft × 0.3048 = m
ft·lbf × 1.355818 = J
gr × 0.06479891 = g
in × 2.54 = cm
kWh × 3 600 000 = J
lb × 0.4535924 = kg
lbf × 4.448222 = N
lbf/ft × 14.59390 = N/m
lbf·in × 0.1129848 = N·m
lbf/in^2 × 6894.757 = Pa
mph × 1.609344 = km/h
qt × 0.9463529 = L

Temperature: $(T_{\cdot F} - 32) \times 5/9 = T_{\cdot C}$

Temperature: $(T_{\cdot C} \times 9/5) + 32 = T_{\cdot F}$

Ballistic Tests of Used Soft Body Armor

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A sample of 24 ballistic resistant undergarments (soft body armor) from a production lot of 1500 originally distributed to 15 police departments throughout the United States in 1975 for issue to officers as part of a Law Enforcement Assistance Administration demonstration project, was tested for V_{50} ballistic limit. The program was a joint effort of the U.S. Department of Justice National Institute of Justice and the National Research Council of Canada Public Safety Project Office. Tests of ballistic limit were conducted on virgin armor that were never issued, and armor showing evidence of light, moderate, and heavy wear both dry and while wet. The results show that armor does not lose ballistic efficiency as a consequence of age.

Key words: ballistic limit; ballistic-resistant body armor; ballistic testing; body armor; Kevlar; soft body armor

1. INTRODUCTION[1]

Soft body armor suitable for routine full time use by police officers became available in quantity in the mid 1970's following development by the National Institute of Justice (NIJ), previously the National Institute of Law Enforcement and Criminal Justice of the Law Enforcement Assistance Administration. In the interim, soft body armor manufactured from Kevlar[2] aramid fiber fabric has gained widespread use. While

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[1]The use of trade names in this report does not constitute endorsement by the National Bureau of Standards, the U.S. Department of Justice, or any other government agency; nor does it imply that a product is necessarily best suited for the intended use.

[2]Registered trade name of E. I. Du Pont de Nemours & Co., Inc.

exact statistics are not available it is estimated that more than 50 percent of the nation's police have been issued body armor, or have purchased it themselves.

Many police departments are currently continuing to use armor that was purchased prior to 1975. Although there has never been a reported incident of armor manufactured from Kevlar failing to protect an officer when assaulted with a weapon having a ballistic threat equal to or less than the rated protection of the armor, those departments with older armor are increasingly concerned with the effect of age and wear upon Kevlar fabric.

During the last year, the NIJ Technology Assessment Program (TAP) Information Center, and the National Research Council of Canada (NRC) Public Safety Project Office have received numerous inquiries from police agencies questioning whether it is necessary to replace older existing armor to be sure that their officers are properly protected. In response to these questions, NIJ and NRC requested that the National Bureau of Standards Law Enforcement Standards Laboratory (LESL) collaborate with the TAP Information Center to conduct tests of soft body armor that had been in service for extended periods of time. The discussion that follows describes the testing program that was conducted and presents the results of this effort.

2. BACKGROUND

The NIJ, aware of the rapidly increasing number of officer fatalities through handgun assault during the late 1960's and early 1970's recognized that the physical properties of Kevlar held potential for ballistic resistance. Preliminary experiments demonstrated that Kevlar was highly efficient in ballistic resistance and NIJ launched an effort to develop soft body armor that was suitable for routine full time use by police officers.

The objective of the development effort was to design armor that would protect officers from the most common handgun threats of that time, the 38 caliber bullet at a velocity of 850$\pm$50ft/s, and the 22 caliber bullet at a velocity of 1050$\pm$50 ft/s. Experiments were conducted to determine the minimum number of layers of Kevlar required

to provide the desired ballistic protection, and it was found that seven layers were suitable. Since Kevlar fabric was not available in commercial quantity at the time, NIJ awarded contracts to several weavers to produce large quantities of the fabric. Following this, NIJ awarded contracts to several manufacturers to produce ballistic-resistant undergarments in accordance with the NIJ design specification. A total of 3000 such garments of two designs were manufactured, together with 2000 additional garments of several other types of soft body armor.

In order to prove that the new armor was effective in protecting the officers from handgun assault, and that it was suitable for full time routine use throughout the United States, NIJ distributed the armor to 15 cities throughout the United States. The resulting field test verified that all of the objectives of the NIJ development effort had been met [1][3], and body armor manufacturers began to actively market the new armor.

During the time that NIJ developed the new soft body armor, LESL developed a performance standard for body armor, which was promulgated by NIJ as a voluntary national standard in 1973. Since then, the NIJ standard, which has been revised twice to remain current with technology, has been widely used both domestically and internationally as the basis upon which body armor is purchased.

During the course of its development effort, NIJ was careful to document the details of the experimental effort. Thus, data were available concerning the ballistic-resistant characteristics of the original production lots that would enable valid conclusions concerning the effect, of age and wear, if any, upon the ballistic efficiency of those vests if samples could be obtained for laboratory tests.

The TAP Information Center contacted each of the 15 cities that had been given undergarments during the NIJ demonstration program and requested a search of property records to determine if any of the vests were still in their possession. In addition, NIJ examined its own property records and requested that other Federal agencies that purchased armor in parallel with the NIJ program do the same.

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[3]Numbers in brackets refer to references in section 8 of this report.

Five cities located armor from the original NIJ purchase, some still in actual use and some in inventory. Similarly, NIJ and two other Federal agencies were able to locate armor manufactured at that time, some of which was never worn.

3. BALLISTIC RESISTANCE TEST METHODS

The physical characteristics of Kevlar fiber, and the fabric woven from it, vary somewhat from lot to lot and even within a lot, as with any item of manufacture. As a consequence, when multiple layers of fabric are used to construct soft body armor the ballistic resistance of individual vests of the same design varies from one to another.

The NIJ standard for ballistic resistant police body armor establishes minimum performance requirements. To this end, body armor is tested by firing specific types of bullets against armor samples using closely controlled velocities. Armor that is not penetrated by the required test rounds and does not deform more than 1.73 in upon impact is considered to meet the requirements of the standard. Because soft body armor manufactured from fabric is known to lose ballistic efficiency when it is wet, and since officers do get wet, the armor model is tested both dry and while wet.

The NIJ standard for body armor can be used as the basis for tests to determine whether armor complies with the minimum performance requirements as specified, but the test results do not provide a knowledge of the ultimate ballistic protection that a given sample of body armor may provide. Frequently manufacturers will incorporate more layers of fabric than required for minimum performance to ensure that the armor will meet the ballistic requirements even if a given lot of fabric is slightly less ballistically efficient than normal.

In order to examine the relative ballistic performance of armor, rather than simply verifying minimum performance, it becomes necessary to use a different method of test. The armor industry has typically used the V_{50} ballistic limit as the means of comparing the ultimate performance of armor materials.

V_{50} ballistic limit is the velocity at which a specific projectile (bullet) is expected to penetrate the armor half of the time.

The ballistic limit of armor is most frequently conducted using the procedures of MIL-STD-662D [2]. Essentially, the specified test projectile is fired at the armor over a range of impact velocities and the specimen examined after each impact to determine whether the projectile has penetrated the armor or not. While the standard permits different velocity ranges from the highest velocity test round to the lowest, a total velocity range of 125 ft/s is most commonly used for the test. In practice, the first projectile is fired at a velocity controlled so as to yield an impact velocity near that of the expected V_{50}. If the first projectile penetrates the velocity of the second test round is reduced and the impact point examined for penetration. Conversely, if the first projectile does not penetrate, the velocity of the second round is increased and the impact point examined for penetration. The objective is to fire a total of 10 projectiles at various velocities to obtain 10 impacts; five of which penetrate and five of which do not within an overall velocity range of 125 ft/s. The V_{50} ballistic limit is then calculated as the average velocity of the 10 test rounds.

The test results presented in this report were obtained using the procedures of MIL-STD-662D.

The NIJ standard for police body armor requires the evaluation of both the penetration resistance of body armor and the deformation of the armor caused by the bullet impact. The deformation, which is measured as the depth of the indentation in the clay backing material at the point of a nonpenetrating impact, is determined to ensure that an individual wearing the armor will be protected from blunt trauma.

Specifically, NILECJ-STD-0101.01, Ballistic Resistance of Police Body Armor [3] (the test method used to obtain some of the results presented in this report) requires that the deformation not exceed 1.73 in for Type I armor when impacted with a 40 grain lead round nose 22 caliber bullet at a velocity of 1050 ± 50 ft/s and a 158 grain lead round nose 38 caliber bullet at velocity of 850 ± 50 ft/s.

The deformation measurements were included in the experimental design to determine whether deformation might be an early indicator of ballistic deterioration, should used armor exhibit a significant loss in ballistic efficiency.

4. TEST SPECIMENS

The 24 sets of body armor tested in this program were all of the same design as shown in figures 1a and 1b and the vests were constructed of seven layers of 1000 denier, 31x31 plain weave Kevlar fabric, which was waterproofed with Zepel D^2.

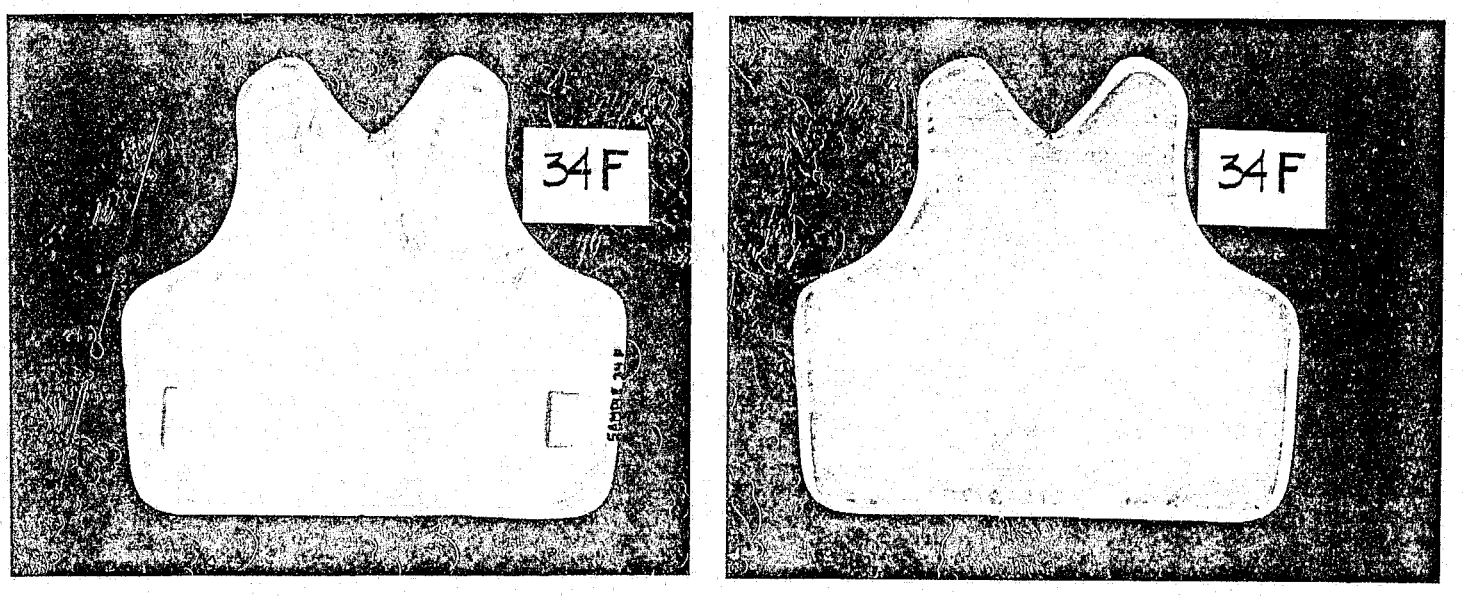

Figure 1a. Front of vest outside and inside.

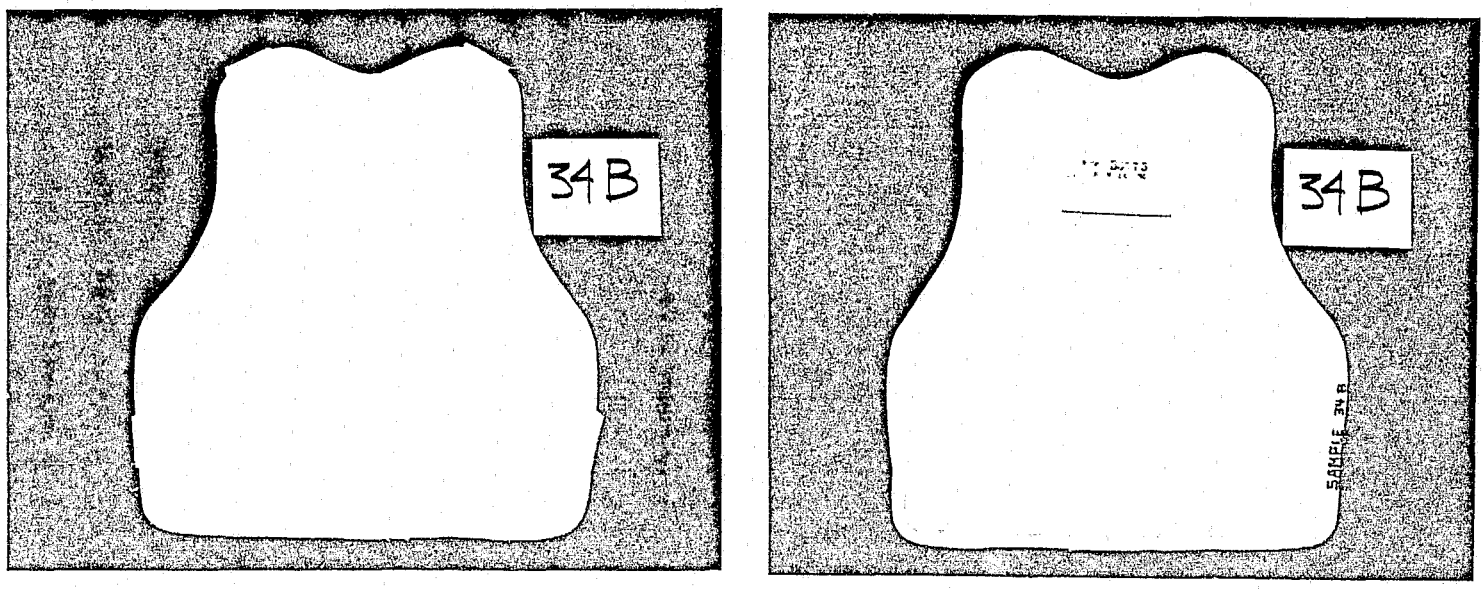

Figure 1b. Back of vest outside and inside.

During manufacture, the two outer layers of Kevlar fabric and the exterior cover were cut to the finished size. The five interior layers were cut slightly smaller than the outer layers. The interior Kevlar layers were first stitched together at a number of points near the edge of the fabric. The interior layers were then placed between the two outer Kevlar layers and the front cover and the assembly was completed by sewing bias tape around the entire edge attached to the outer Kevlar layers, which extended approximately one-half inch beyond the edge of the interior layers.

The back panel construction was identical to that of the front panel as described above; however, in addition, the back panel was reinforced by vertical stitching from top to bottom at intervals of approximately 4 in from one side to the other.

Each vest was clearly labeled "LEAA Prototype Protective Garment," which enabled verification that the garment was indeed from the original LEAA demonstration production lot.

While the property records of the five police departments were sufficiently accurate to locate the test specimens, it was generally not possible to obtain accurate information concerning the wear and maintenance details for the individual vests. This

was a consequence of the fact that the individuals that were issued the vests were no longer on their respective forces and efforts to locate the officers were unsuccessful.

It was possible to obtain limited use information for only seven of the vests. Five of the vests (15, 17, 18, 20, and 21) were obtained from a department with a very hot, moderately humid climate. These vests were issued upon receipt from LEAA in 1975 and were still in service when recalled for testing in April 1986--a service period well over 10 years. The department policy was one of voluntary use, however, the department believes that the officers that wore the vests did so full time except for the hottest months of the summer.

Vest 6 which came from a department with a generally hot, humid climate, was worn by three different officers. The first officer had the vest for over a year and one-half; however, its use was not known. The second officer wore it full time while on duty for approximately two years, wiping it with a damp sponge and soap and never machine washing it. The last officer wore it for a one-year period but the extent of wear is not known.

Vest 9 which came from a department with a very hot humid climate, was used by the first officer of issue for over three and one-half years. There is no information on the extent of use. The vest was subsequently issued to an auxiliary officer that wore it full time while on duty for a period of five years. However, this officer was only on duty a few days each month.

In the absence of detailed use information, it became necessary to rely upon visual inspection to estimate the extent of use. Eight of the 24 test specimens were unused. Representatives of NIJ, LESL, and the TAP Information Center examined each of the remaining 16 specimens that had been used. It was possible to separate the vests into three groups:

- Four exhibited light wear
- Four exhibited moderate wear
- Eight exhibited heavy wear

Once the test specimens were classified in accordance with use (unused, light wear, moderate wear, heavy wear), they were randomly assigned to two test groups. One group was scheduled for ballistic test using 38 caliber ammunition, the other for tests using 22 caliber ammunition. Finally, half of the vests in each group were scheduled for ballistic tests while wet and the other half for ballistic tests while dry.

5. TEST RESULTS

The testing of used armor was conducted by the H. P. White Laboratory, Inc., Street, Maryland, during the period from May 22 to June 10, 1986. Representatives of the TAP Information Center, the National Research Council of Canada, and LESL witnessed all testing.

The test samples were mounted at a distance of 16.0 ft from the test weapon on clay backing as specified by NILECJ-STD-0101.01 to produce a zero degree angle of obliquity. The first shots on each panel were to determine the back face signature (clay deformation) in accordance with NILECJ-STD-0101.01 after which the V_{50} of the panel was determined. Light screens were positioned at 6.5 and 9.5 ft which, in conjunction with an elapsed time counter (chronograph), were used to determine all bullet velocities at 8.0 ft.

In conducting ballistic limit tests of the 24 samples, the front and back panels of each vest were tested separately. Every effort was made to obtain 10 valid impacts for the determination of V_{50} ballistic limit. However, there were a number of instances in which the shot placement was such that it was not possible to obtain 10 valid impacts and, in these cases, 8 shot V_{50} ballistic limit data are reported. Similarly, there were instances in which the inspection of the vest at a later date revealed that an impact used to calculate a 10 shot V_{50} ballistic limit was not a valid impact and the data was recalculated on the basis of an 8 shot V_{50}.

Table 1 summarizes the V_{50} ballistic limit for each vest tested using 38 caliber bullets. Following completion of the tests, vest 22 was reinspected and found to contain eight layers of Kevlar, rather than the specified seven layers. Table 2

presents the blunt trauma deformation measurements that were obtained using 38 caliber bullets.

Table 1. V_{50} ballistic limit data, 38 caliber, 158 grain, lead round nose bullet (V_{50} expressed in feet per second)

Unused vests		Light wear vests			Moderate wear vests			Heavy wear vests		
Sample	V_{50}	Sample	V_{50}	Variation from unused vest average (percent)	Sample	V_{50}	Variation from unused vest average (percent)	Sample	V_{50}	Variation from unused vest average (percent)
1F	1074	33F	1104	+3.2	10F	1108	+3.6	17F	1153	+7.8
1B	1075	33B	1135	+6.1	10B	1165	+8.9	17B	1075	+0.5
23F	1036	12F[c]	1126[c]	+5.2	30F[c]	1120	+4.7	31F	1131	+5.7
24B	1050	12B[c]	1112[c]	+3.9	30B[c]	1118	+4.5	31B	1152[b]	+7.7
4F[c]	1088	Average	1119	+4.6	Average	1128	+5.4	18F[c]	1080	+0.9
4B[c]	1095							18B[c]	1074	+0.4
Average	1070							13F[c]	1159[b]	+8.3
22F[a,c]	1161[a]							13B[c]	1129[b]	+5.5
22B[a,c]	1193							Average	1119	+4.6

[a]Sample 22 contained eight layers of fabric, excluded from average.

[b]Eight shot V_{50} determination.

[c]Tested wet.

Table 2. Deformation measurements, 38 caliber projectile

Unused vests			Light wear vests			Moderate wear vests			Heavy wear vests		
Sample	Average Impact Velocity (ft/s)	Deformation (in)	Sample	Average Impact Velocity (ft/s)	Deformation (in)	Sample	Average Impact Velocity (ft/s)	Deformation (in)	Sample	Average Impact Velocity (ft/s)	Deformation (in)
1F	895	1.65	33F	880	1.40	10F	855	1.50	17F	860	1.50
	887	1.50		893	1.40		885	1.60		872	1.60
1B	850	1.60	33B	874	1.50	10B	885	1.60	17B	867	1.50
	877	1.45		888	1.35		898	1.45		889	1.30
23F	867	1.50	12F[a]	892	1.45	30F[a]	837	1.45	31F	875	1.45
	884	1.50		897	1.50		839	1.65		881	1.50
24B	895	1.50	12B[a]	842	1.70	30B[a]	854	1.40	31B	877	1.35
	871	1.60		823	1.65		837	1.60		885	1.50
4F[a]	888	1.60							18F[a]	872	1.60
	866	1.60								877	1.60
4B[a]	867	1.60							18B[a]	882	1.65
	869	1.60								882	1.50
22F[a]	896	1.60							13F[a]	821	1.50
	875	1.40								828	1.60
22B[a]	881	1.30							13B[a]	837	1.50
	902	1.45								834	1.55

[a]Tested wet.

Note: All velocity measurements rounded to nearest foot per second.

Table 3 summarizes the V_{50} ballistic limit for each vest tested using 22 caliber bullets, and table 4 presents the blunt trauma deformation measurements obtained with 22 caliber bullets.

Table 3. V_{50} Ballistic Limit Data
.22 caliber, 40 grain, lead round nose bullet
(V_{50} expressed in feet per second)

Unused vests		Light wear vest			Moderate wear vests			Heavy wear vests		
Sample	V_{50}	Sample	V_{50}	Variation from unused vest average (percent)	Sample	V_{50}	Variation from unused vest average (percent)	Sample	V_{50}	Variation from unused vest average (percent)
2F	1179	15F	1219	+1.6	32F	1238	+3.2	20F	1160	-3.3
2B	1203	15B	1267	+5.6	32B	1224	+2.0	20B	1172	-2.3
25F	1200	21F[b]	1214	+1.2	7F[b]	1183	-1.4	8F	1200	0
25B	1217	21B[b]	1239	+3.3	7B[b]	1251	+4.3	8B	1205	+0.4
3F[b]	1169	Average	1235	+2.9	Average	1224	+2.0	9F	1183	-1.4
3B[b]	1164							9B	1154	-3.8
26B[b]	1260							6F	1182	-1.5
27F[b]	1210							6B	1137[a]	-5.3
Average	1200							Average	1174	-2.2
Dry retest, not included in average								Initial wet test, not included in average		
3F	1102							9F[b]	1183	-1.4
3B	1182							9B[b]	1099	-8.4
								6F[b]	1075[a]	-10.4
								6B[b]	1145[a]	-4.6

[a]Eight shot V_{50} determination.

[b]Tested wet.

Table 4. Deformation measurements, 22 caliber projectile

Unused vests			Light wear vests			Moderate wear vests			Heavy wear vests		
Sample	Average Impact Velocity (ft/s)	Deformation (in)	Sample	Average Impact Velocity (ft/s)	Deformation (in)	Sample	Average Impact Velocity (ft/s)	Deformation (in)	Sample	Average Impact Velocity (ft/s)	Deformation (in)
2F	1064	0.80	15F	1054	0.80	32F	1029	0.90	20F	1075	0.70
	1063	0.85		1115	0.90		1085	0.85		1067	0.65
2B	1096	0.90	15B	1101	0.55	32B	1066	0.80	20B	1057	0.80
	1063	0.85		1083	0.60		1068	0.80		1063	0.70
25F	1077	0.85	21F[a]	1058	0.80	7F[a]	1054	0.80	8F	1058	0.85
	1054	0.80		1083	0.85		1085	0.80		1081	0.75
25B	1051	0.80	21B[a]	1066	0.80	7B[a]	1040	0.80	8B	1040	0.75
	1070	0.85		1066	0.75		1038	0.85		1081	0.25
3F[a]	1049	0.85							9F[a]	1059	0.20
	1071	0.95								1053	0.75
3B[a]	1071	0.75							9B[a]	1095	0.80
	1103	0.80								1060	0.80
26B[a]	1083	0.75							6F[a]	1054	b
	1073	0.70								1049	b
27F[a]	1101	0.85							6B[a]	1068	0.80
	1038	0.75								1085	0.65
	1064	0.75									

[a]Tested wet.

[b]No measurement, test round penetrated armor.

Note: All velocity measurements rounded to nearest foot per second.

Table 5 expands upon the ballistic limit data summarized in table 1, to include the velocity of the highest velocity nonpenetrating round (H_p), the velocity of the lowest velocity complete penetration round (L_c) and the velocity range of mixed results of penetrating and nonpenetrating rounds for 38 caliber bullets.

Table 5. Complete ballistic limit data, 38 caliber

Unused vests				
Sample no.	V_{50} (ft/s)	H_p (ft/s)	L_c (ft/s)	Range mixed (ft/s)
1F	1074	1113	1031	82
1B	1075	1073	1075	N/A
23F	1036	1083	988	95
24B	1050	1079	1036	43
4F[a]	1088	1109	1064	45
4B[a]	1095	1087	1105	N/A
22A[a]	1161	1147	1170	N/A
22B[a]	1193	1238	1149	89

Medium wear vests				
Sample no.	V_{50} (ft/s)	H_p (ft/s)	L_c (ft/s)	Range mixed (ft/s)
10F	1108	1163	1091	72
10B	1165	1220	1101	119
30F[a]	1120	1165	1093	72
30B[a]	1118	1138	1093	45

Light wear vests				
Sample no.	V_{50} (ft/s)	H_p (ft/s)	L_c (ft/s)	Range mixed (ft/s)
33F	1104	1181	1062	119
33B	1135	1167	1111	56
12F[a]	1126	1113	1113	0
12B[a]	1112	1097	1095	2

Heavy wear vests				
Sample no.	V_{50} (ft/s)	H_p (ft/s)	L_c (ft/s)	Range mixed (ft/s)
17F	1153	1163	1154	9
17B	1075	1107	1062	45
31F	1131[b]	1174	1060	114
31B	1152[b]	1208	1132	76
18F[a]	1080	1097	1064	33
18B[a]	1074[b]	1097	1062	35
13F[a]	1159[b]	1222	1158	64
13B[a]	1129[b]	1210	1103	107

[a]Tested wet.

[b]Eight shot V_{50}.

Table 6 expands upon the ballistic limit data summarized in table 3, including H_p, L_c, and range of mixed velocities for 22 caliber bullets.

Table 6. Complete ballistic limit data, 22 caliber

Unused vests				
Sample no.	V_{50} (ft/s)	H_p (ft/s)	L_c (ft/s)	Range mixed (ft/s)
2F	1179	1202	1165	37
2B	1203	1238	1188	50
25F	1200	1245	1174	71
25B	1217	1255	1176	79
3F[a]	1169	1176	1152	24
3B[a]	1164	1195	1143	52
26B[a]	1260	1288	1232	56
27F[a]	1210	1238	1160	78
Retest (Dry)				
3F	1102	1085	1085	0
3B	1182	1220	1170	50

Medium wear vests				
Sample no.	V_{50} (ft/s)	H_p (ft/s)	L_c (ft/s)	Range mixed (ft/s)
32F	1238	1268	1215	53
32B	1224	1258	1192	66
7F[a]	1183	1156	1154	02
7B[a]	1251	1261	1230	31

Light wear vests				
Sample no.	V_{50} (ft/s)	H_p (ft/s)	L_c (ft/s)	Range mixed (ft/s)
15F	1219	1220	1220	0
15B	1267	1290	1260	30
21F[a]	1214	1242	1198	44
21B[a]	1239	1248	1240	8

Heavy wear vests				
Sample no.	V_{50} (ft/s)	H_p (ft/s)	L_c (ft/s)	Range mixed (ft/s)
20F	1160	1147	1145	2
20B	1172	1174	1172	2
8F	1200	1222	1176	46
8B	1205	1220	1195	25
9F[a]	1183	1181	1154	27
9B[a]	1099[b]	1147	1075	72
6F[a]	1075[b]	1091	1049	42
6B[a]	1145[b]	1172	1115	57
Retest (Dry)				
9F	1183	1198	1160	38
9B	1154	1178	1136	42
6F	1182[b]	1192	1155	37
6B	1137[b]	1165	1143	22

[a]Tested wet.

[b]Eight shot V_{50}.

Appendix A presents the raw data for each sample that was tested using 38 caliber projectiles, noting the impact velocity of each bullet that was fired to determine the V_{50} ballistic limit, whether or not it penetrated, and identifies those test rounds used to calculate the V_{50} ballistic limit. Test rounds associated with deformation testing (see tables 2 and 4) are not included. Appendix B presents the same penetration data as appendix A but for 22 caliber projectiles under the same limitations as appendix A.

Those test rounds reported in appendix A and B that were not used to obtain the V_{50} ballistic limit were excluded from calculation for a variety of reasons, including 1) hitting too close to an edge or prior hit, 2) projectile yaw, and 3) outside of the desired maximum velocity range.

6. DISCUSSION

When tested following the procedures of NILECJ-STD-0101.01, the deformation measurements that were made for all samples were well within the specified maximum limit of 1.73 in. There was no apparent difference between dry testing and wet testing. From these tests we concluded that impact deformation does not appear to hold promise as an early indicator of loss of ballistic resistant efficiency.

The interpretation of the V_{50} ballistic limit data for the vests that were evaluated can be considered somewhat subjective because the data are too limited to permit rigorous statistical analysis. However, the following was derived from this series of tests.

The average V_{50} ballistic limit for the 38 caliber test rounds of the 10 year old unused armor is 1070 ft/s, excluding vest 22, which consists of eight layers of Kevlar. The standard deviation of the V_{50} is 22.6 ft/s, with an overall range of 59 ft/s. There is no obvious difference within any of the four wear groups (new, light wear, moderate wear, or heavy wear) between tests conducted with the armor wet or dry.

When the V_{50} ballistic limit of each of the used vests is compared to the average of the unused vests of the same construction, in all cases the used vest has a higher V_{50}.

When the average V_{50} of the three used vest groups (wet and dry testing averaged together) is compared with that of the unused armor, each of the three used vest groups exhibit V_{50} roughly 5 percent higher.

V_{50} ballistic limit data for the 158-grain lead round nose bullet was not reported in testing conducted by Edgewood Arsenal during the earlier LEAA development effort; however, partial data [4] imply a V_{50} ballistic limit on the order of 1000 ft/s. Since the tests were conducted with fabric not sewn together, one would expect a higher V_{50} for the finished vests that were tested, and the values of V_{50} ballistic limit that were obtained are consistent with the earlier data.

It is perhaps of more interest to examine the test results in terms of the velocity of the lowest complete penetration for each panel, for this gives a better idea of absolute ballistic resistance relative to the rated threat level. The test velocity for the determination of penetration for a Type I vest is 850±50 ft/s, or a maximum velocity of 900 ft/s. With one exception, all of the vests that were tested demonstrated a velocity for the lowest velocity complete penetration more than 150 ft/s above that required for minimum performance. Even the poorest performing armor sample (vest 23 front) exceeded the 900 ft/s requirement by a velocity of 88 ft/s.

As with the 38 caliber testing of V_{50} ballistic limit, there did not appear to be any overall difference between 22 caliber tests conducted wet and dry, other than discussed below. The overall average V_{50} ballistic limit using the 22 caliber 40 grain lead round nose bullet was 1200 ft/s with a standard deviation of 31 ft/s and an overall range of 96 ft/s. Earlier data from Edgewood Arsenal [3] reports a V_{50} ballistic limit for seven layers of Kevlar 1000 denier fabric of 1084 ft/s. Again, these tests used fabric only and the ballistic limit of the fabricated vests would be expected to exceed that reported. The same Edgewood report presents a V_{50} ballistic limit of seven layers of 1140 denier Kevlar of 1213 ft/s. This fabric is similar to 1000 denier in ballistic efficiency, although, it was not treated for water repellency. Since the overall ballistic efficiency of treated Kevlar is known to be less than untreated, the average V_{50} of 1200 ft/s is reasonable for the unused armor that was tested in this program.

When first tested wet, the front panel of vest 6 was penetrated at velocities of 1054 and 1049 ft/s and the V_{50} ballistic limit was 1075 ft/s; well below the 1100 ft/s upper limit of threat Type I protection (1050±50 ft/s). Likewise, the V_{50} ballistic limit of the back panel of vest 9 was 1099 ft/s which is marginal performance at best. Since all other vests tested with 22 caliber bullets were found to have V_{50} ballistic

limits well in excess of 1100 ft/s, the data for vests 6 and 9 were suspect. Similarly, vest 3, also tested wet, appeared to have a somewhat low V_{50} ballistic limit, when compared to the other unused vests.

Vests 3, 6, and 9 were allowed to dry in a well ventilated, controlled environment for several days, and once feeling dry to touch, were retested dry for ballistic limit using the 22 caliber ammunition. The two panels in most question, 9B and 6F, when retested dry, demonstrated V_{50} ballistic limits well above 1100 ft/s, as did the lowest velocity complete penetrating rounds. The other parts of these vests continued to demonstrate satisfactory V_{50} ballistic limit and lowest complete penetrating velocity, when dry.

The retest of vest 3 was not conclusive. The V_{50} ballistic limit of the back panel increased slightly when retested; however, that of the front panel decreased. While the placement of the bullet impacts during retest were sufficiently distant from prior impact locations to constitute fair hits, it remains possible that the previous testing prevented obtaining valid V_{50} data in the second set of tests (see fig. 2).

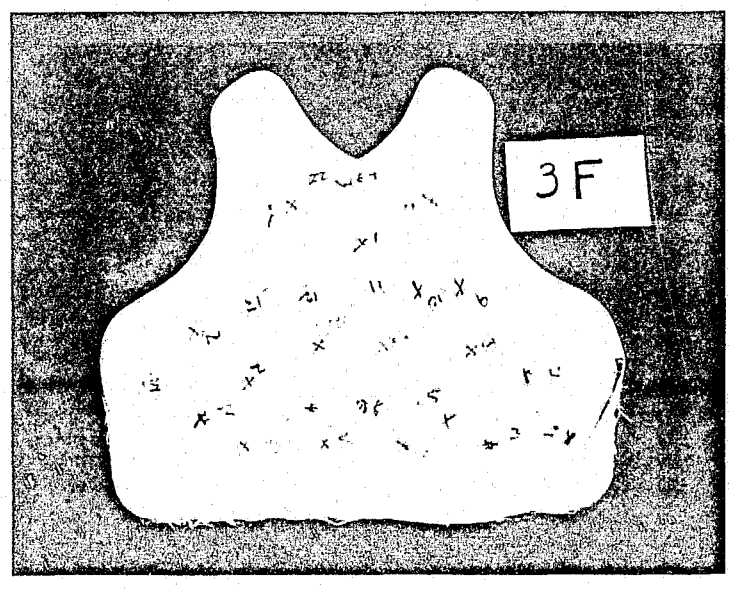

Figure 2. Front of vest 3 after being shot.

Overall, as with the 38 caliber testing, the V_{50} ballistic limit of the light and moderate wear samples tested with 22 caliber bullets increased when compared with the average of the unused samples. The heavily worn vests had an average V_{50} ballistic limit of 1174 ft/s (using data for vest 6 and 9 tested dry), 2.2 percent less than the average 1200 ft/s ballistic limit of the unused vests.

7. CONCLUSIONS

Body armor manufactured from Kevlar fabric retains full ballistic efficiency when stored under typical warehouse conditions for periods of time in excess of 10 years. It may well be, as anticipated, that such armor has an unlimited shelf life.

Deformation measurements using wet or dry armor do not appear to provide significant information as a means of identifying decreased ballistic efficiency of used armor manufactured from Kevlar fabric.

Two of the sample vests that were tested for ballistic limit did not appear to have adequate waterproofing. It is not known whether this was a consequence of heavy wear or improper water repellent treatment at the time of manufacture.

Both the 38 caliber and 22 caliber ballistic limit data support an apparent trend of improved ballistic efficiency as a consequence of light to moderate wear and possibly a slight decrease in ballistic efficiency as a result of heavy wear. The limited data that were obtained and the variation of ballistic efficiency within lots of Kevlar fabric is such that it is very difficult to say with certainty that the difference between the V_{50} of unused and heavily used vests is solely a consequence of wear, or due to the individual samples. Recent data obtained from the U.S. Army [5] for V_{50} ballistic limit of 16 production lots of Kevlar fabric (12-layer test samples tested using the 22 caliber fragment simulator) demonstrate ranges of V_{50} ballistic limits of more than 6 percent between individual lots.

The possible trend of decreased ballistic efficiency of armor following heavy use, coupled with the identification of at least two armor panels that lacked waterproofing,

strongly suggest that it is prudent for any police department to inspect the vests worn by its officers on at least an annual basis. Representative samples of vests showing extremely heavy wear should be tested for ballistic performance. Such tests should be conducted with the vests in the wet condition. In the interest of minimizing testing cost, it is recommended that such testing be limited to the six shot test sequence specified by the current edition of the NIJ Standard using a single test round (22 caliber for Type I vests and 9 mm for Level IIA, II, and IIIA vests).

8. REFERENCES

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[3] Ballistic resistance of police body armor. NILECJ-STD-0101.01. National Institute of Justice, U.S. Department of Justice, Washington, DC 20531; 1978 March. Superseded by NIJ Standard-0101.02, Ballistic Resistance of Police Body Armor dated March 1985.

[4] Prather, R. N., Swain, C. L., Hawkins, C. E. Back face signatures of soft body armors and the associated trauma effects. RCSL-TR-77-55. Chemical Systems Laboratory, Aberdeen Proving Ground, MD; 1977 November.

[5] Personal communication with the Defense Personnel Support Center, Philadelphia, PA.

APPENDIX A

V_{50} Ballistic Limit Test Data

Seven Layer Kevlar Soft Body Armor

38 Caliber, 158 Grain, Lead Round Nose Projectile

Sample 1 (unused); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
4	1026	3	1143	3	1005	6	1075[a]
5	1081	6	1218	4	995	8	1138[a]
8	1077[a]	7	1085[a]	5	1073[a]	10	1089[a]
10	1081a	9	1081[a]	7	906	11	1111[a]
13	1075a	11	1064[a]	9	1022[a]	13	1178
14	1113[a]	12	1031[a]	12	1058[a]	15	1158
16	1036[a]	15	1097[a]	14	1026[a]	16	1124[a]
				17	1031[a]		

Sample 4 (unused); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
4	1109[a]	3	1202	4	1014	3	1143[a]
9	1073[a]	5	1188	5	1020	6	1156[a]
10	1068[a]	6	1070[a]	8	984	7	1105[a]
11	1051[a]	7	1149[a]	9	1054[a]	10	1111[a]
12	1022[a]	8	1130[a]	12	1054[a]	11	1130[a]
		13	1149[a]	13	977		
		14	1064[a]	14	1054[a]		
				15	1024		
				16	1087[a]		
				17	1058[a]		

[a]Used to calculate V_{50} ballistic limit.

Sample 10 (moderate wear); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1075[a]	4	1041[a]	5	1077	7	1277
5	1163a	6	1103[a]	6	1073	8	1160[a]
8	949	7	1132[a]	10	974	9	1208[a]
9	932	11	1141[a]	11	1136[a]	12	1210[a]
10	1119[a]	12	1145[a]	13	1158[a]	15	1210[a]
13	1056[a]			14	1113[a]	18	1101[a]
14	1053[a]			16	1136[a]		
				17	1070		
				19	1220[a]		

Sample 12 (Light wear); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
10	1070[a]	2	1184[a]	3	861	6	1134[a]
11	1062[a]	9	1174[a]	4	1089[a]	8	1165[a]
12	1113[a]	15	1163[a]	5	1040	10	1095[a]
13	1107[a]	16	1192	7	1062[a]	14	1160[a]
14	1111[a]	17	1113[a]	9	1097[a]	16	1192
		18	1165[a]	11	982	17	1138a
				12	1085[a]		
				13	1097[a]		
				15	964		

[a]Used to calculate V_{50} ballistic limit.

Sample 13 (heavy wear); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
5	1103[a]	4	1158[a]	5	1210[a]	3	1143
7	1124a	6	1186[a]	6	1130[a]	4	1103[a]
8	871	9	1165	11	1085[a]	7	1126[a]
12	1064	11	1165[a]	14	1128[a]	8	1172
13	978	16	1235	17	1073	9	1138
14	1147[a]	17	1170[a]			10	1163
15	1087	19	1215			12	1156
18	1222[a]					13	1132[a]
						15	1117[a]
						18	1186
						19	1143
						20	1174

Sample 17 (heavy wear); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1089[a]	7	1285	6	1107[a]	3	1266
4	1119[a]	12	1232	11	1040[a]	4	1245
6	1132[a]	13	1192[a]	13	1007	5	1220
8	1107[a]	14	1192[a]	14	1058[a]	7	1210
9	840	15	1215	17	1022[a]	8	1083[a]
10	722	16	1154[a]	18	1079[a]	9	1220
11	867	18	1186[a]	19	1003	10	1149
17	1163[a]	20	1200[a]			12	1103[a]
19	1071					15	1130[a]
						16	1068[a]
						20	1062[a]

[a]Used to calculate V_{50} ballistic limit.

Sample 18 (heavy wear); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
5	1097[a]	3	1109[a]	3	1060[a]	5	1079[a]
6	1034[a]	4	1122[a]	4	1066[a]	6	1097[a]
9	1031[a]	7	1130[a]	7	1008[a]	8	1070[a]
11	997	8	1099[a]	10	1097[a]	9	1062[a]
12	1020[a]	10	1014[a]	11	1073[a]	13	1130[a]
14	1089[a]	13	1154	12	995		

Sample 22 (unused); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1073	6	1261	3	1156[a]	5	1192[a]
4	1047	8	1176[a]	4	1077	7	1261[a]
5	1103[a]	12	1120[a]	6	1195[a]	10	1224[a]
7	992	13	1212[a]	8	1058	11	1149[a]
9	1132[a]	14	1227[a]	9	1238[a]	15	1218[a]
10	934	19	1192[a]	12	1099		
11	1079			13	1149[a]		
15	1085			14	1111		
16	1132[a]			16	1149[a]		
17	1089						
18	1117[a]						
20	1147[a]						

[a]Used to calculate V_{50} ballistic limit.

Sample 23/24 (unused); tested dry

Front (23)				Back (24)			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	950	4	1255	4	1017[a]	3	1117
9	1062a	5	1119	5	1029[a]	7	1036[a]
10	958	6	1034[a]	6	971	8	1049[a]
11	1045[a]	7	1122	9	970	10	1045[a]
14	1007[a]	8	988[a]	14	965	11	1083[a]
16	948	12	1047[a]	16	1053[a]	12	1107[a]
17	992[a]	13	1002[a]	17	1079[a]	13	1156
18	1083[a]	15	1095[a]	18	1005[a]	15	1245

Sample 30 (medium wear); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
5	1081[a]	3	1113[a]	5	1134[a]	3	1134[a]
6	1105[a]	4	1156	7	1138[a]	4	1093[a]
8	1163[a]	7	1081	8	992	6	1085
9	1165[a]	10	1230	11	1128[a]	9	1210
14	940	11	1184	13	1073[a]	10	1130[a]
17	1083[a]	12	1138[a]	14	982	12	1172[a]
		13	1093[a]	16	914	15	1176[a]
		15	1152[a]	17	1056[a]		
		16	1105[a]				

[a]Used to calculate V_{50} ballistic limit.

Sample 31 (heavy wear); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1134[a]	9	1215	4	1120[a]	6	1271
4	1002	10	1099[a]	5	1093[a]	8	1280
5	1174[a]	11	1224	7	1208[a]	9	1261
6	1097[a]	13	1060[a]	10	958	11	1245
7	1122[a]	15	1165[a]	15	1075	12	1195[a]
8	1105[a]	17	1172[a]	16	1154[a]	13	1181[a]
12	998	18	1181[a]	22	1010	14	1240
14	1147					17	1230
16	1034					18	1240
						19	1136[a]
						20	1132[a]
						21	1299

Sample 33 (Light wear); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	977	6	1130[a]	3	1167[a]	7	1200[a]
4	1068[a]	11	1091[a]	4	1056	8	1183[a]
5	1031	14	1124[a]	5	1073	10	1111[a]
7	1087[a]	15	1062[a]	6	1122[a]	14	1220
8	1181[a]	17	1138[a]	9	998	19	1152[a]
9	861			11	1042	22	1210
10	1056[a]			12	1075[a]	23	1130[a]
12	1101[a]			13	1064		
13	1005			15	1031		
16	1027			16	1012		
				17	1044		
				18	1126[a]		
				20	1089[a]		
				21	1053		

[a]Used to calculate V_{50} ballistic limit.

APPENDIX B

V_{50} Ballistic Limit Test Data

Seven Layer Kevlar Soft Body Armor

22 Caliber, 40 Grain, Lead Round Nose Projectile

Sample 2 (unused); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1163[a]	4	1227[a]	3	1200[a]	8	1316
6	1170a	5	1210[a]	4	1170[a]	10	1266[a]
9	1111[a]	7	1186[a]	5	1224	11	1222[a]
10	1085	8	1165[a]	6	1141[a]	12	1188[a]
11	1202[a]	12	1178[a]	7	1238[a]	14	1220[a]
14	1178[a]	13	1190	9	1310	15	1212[a]
				13	1176[a]		

Sample 3 (unused); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1130	5	1208[a]	5	1156[a]	3	1238
4	1165[a]	6	1198[a]	7	1158[a]	4	1202[a]
7	1143[a]	8	1158[a]	8	1195[a]	6	1178[a]
9	1143[a]	10	1184[a]	13	1117[a]	9	1202
12	1176[a]	11	1152[a]	14	1132[a]	10	1190[a]
13	1165[a]					11	1170[a]
						12	1143[a]

[a]Used to calculate V_{50} ballistic limit.

Sample 3 (unused); retested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
16	1017	14	1176[a]	15	1158[a]	16	1202[a]
17	1068a	15	1145[a]	17	1163[a]	18	1280
18	1066[a]	19	1154[a]	19	1181[a]	21	1232[a]
22	1070[a]	20	1109[a]	20	1220[a]	22	1220[a]
23	1066[a]	21	1085[a]	26	1117[a]	23	1218[a]
24	1085[a]					25	1170[a]

Sample 6 (heavy wear); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1024	1	1054[a]	3	1099	5	1288
4	1007	2	1049[a]	4	1132[a]	6	1250
5	1083[a]	12	1089[a]	7	1172[a]	9	1230
6	1075[a]	14	1109[a]	8	1230	10	1202[a]
7	1091[a]	15	1060[a]	15	1051	11	1208
8	1051			17	1113[a]	12	1208
9	1070[a]			19	1081	13	1181[a]
11	1066[a]			20	1124[a]	14	1115[a]
13	1062					18	1122[a]

Note: Shot 10, no velocity reading.

[a]Used to calculate V_{50} ballistic limit.

Sample 6 (heavy wear); retested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
16	1099	17	1158[a]	25	1040	21	1143[a]
18	1170[a]	19	1240[a]	26	1062	22	1163[a]
20	1149[a]	22	1190[a]	27	1085[a]	23	1202
21	1145[a]	24	1205[a]	28	1068[a]	24	1178[a]
23	1167[a]	25	1208[a]	29	1138[a]	31	1158[a]
26	1192[a]			30	1165[a]		

Sample 7 (moderate wear); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
9	1071	3	1296	6	1186[a]	3	1250[a]
10	1143[a]	4	1274	7	1200[a]	4	1230[a]
11	1124	5	1248[a]	8	1250[a]	5	1176
12	1154[a]	6	1235[a]	9	1250[a]	11	1299[a]
14	1152[a]	7	1184[a]	10	1261[a]	12	1290[a]
16	1149[a]	8	1154[a]			13	1293[a]
18	1156[a]	13	1357				
		15	1282				
		17	1258[a]				

[a]Used to calculate V_{50} ballistic limit.

Sample 8 (heavy wear); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1126[a]	7	1327	3	1200[a]	6	1205[a]
4	1134[a]	8	1268	4	1220[a]	7	1215[a]
5	1186[a]	9	1245[a]	5	1172	11	1215[a]
6	1215[a]	10	1232[a]	8	1210[a]	12	1220[a]
11	1222[a]	12	1245[a]	9	1181[a]	13	1195[a]
		13	1220[a]	10	1186[a]		
		14	1176[a]				

Sample 9 (heavy wear); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
4	1176[a]	3	1154[a]	4	1147[a]	3	1174
7	1158a	5	1202[a]	9	1049[a]	5	1170
8	1181[a]	6	1165	11	1107[a]	6	1145
10	1174[a]	9	1170[a]	13	1101[a]	7	1113[a]
12	1165[a]	11	1188[a]	15	1000	8	1105
		13	1202	16	1093[a]	10	1075[a]
		14	1258[a]			12	1119[a]
						14	1085[a]
						16	1093[a]

[a]Used to calculate V_{50} ballistic limit.

Sample 9 (heavy wear); retested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
16	1134[a]	15	1188[a]	18	1178[a]	17	1200
17	1192[a]	19	1215[a]	22	1138[a]	19	1186[a]
18	1198[a]	20	1195[a]	23	1140[a]	20	1176[a]
22	1149[a]	21	1160[a]	26	1130[a]	21	1136[a]
23	1174[a]	24	1227[a]	27	1143[a]	24	1156[a]
						25	1156[a]

Sample 15 (Light wear); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
8	1128	4	1313	3	1186[a]	5	1285
9	1205[a]	5	1310	4	1202[a]	6	1364
10	1181[a]	6	1277	7	1280[a]	8	1310[a]
12	1186	7	1230[a]	10	1290[a]	9	1299[a]
13	1215[a]	11	1230[a]	14	1245[a]	11	1333
15	1190[a]	14	1261[a]			12	1261[a]
19	1220[a]	16	1277			13	1304[a]
		17	1220[a]			15	1293[a]
		18	1240[a]				

[a]Used to calculate V_{50} ballistic limit.

Sample 20 (heavy wear); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1220	4	1232	4	1147[a]	3	1174[a]
8	1109[a]	5	1232[a]	5	1174[a]	6	1178[a]
9	1149	6	1208[a]	8	1160[a]	7	1195[a]
10	1126	7	1145[a]	9	1170[a]	10	1198[a]
12	1134[a]	11	1160[a]	12	1147[a]	11	1172[a]
13	1134[a]	14	1208[a]				
15	1147[a]						

Sample 21 (light wear); tested wet

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
3	1077	6	1242[a]	3	1220[a]	8	1268[a]
4	1160[a]	10	1232[a]	4	1250	10	1261[a]
5	1232[a]	11	1248[a]	5	1238	12	1240[a]
7	1222	12	1252	6	1261	14	1242
8	1235	13	1222[a]	7	1232[a]	16	1327
9	1242[a]	14	1198[a]	9	1248[a]	17	1224
15	1174[a]			11	1232	18	1264[a]
16	1188[a]			13	1224[a]	19	1252[a]
				15	1198		
				20	1191[a]		

[a]Used to calculate V_{50} ballistic limit.

Sample 25 (unused); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
4	1212[a]	3	1212[a]	6	1130	3	1258[a]
7	1208[a]	5	1188	7	1113	4	1184[a]
11	1245[a]	6	1242	8	1174a	5	1176[a]
15	1170[a]	8	1304	9	1230a	12	1218[a]
18	1122[a]	9	1261	10	1198a	14	1282[a]
		10	1250	11	1198[a]		
		12	1202[a]	13	1255[a]		
		13	1190[a]				
		14	1238[a]				
		16	1277				
		17	1174[a]				

Sample 26/27 (unused); tested wet

Front (27)				Back (26)			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
5	1174[a]	4	1285[a]	3	1222[a]	5	1313[a]
6	1238[a]	7	1268[a]	4	1252[a]	7	1285[a]
1[illegible]	1172[a]	8	1186[a]	6	1282[a]	8	1238[a]
[illegible]	1186[a]	9	1248[a]	9	1242[a]	10	1222
13	1188[a]	10	1160[a]	11	1288[a]	13	1248[a]
						14	1232[a]

[a]Used to calculate V_{50} ballistic limit.

Sample 32 (moderate wear); tested dry

Front				Back			
Partial penetration		Complete penetration		Partial penetration		Complete penetration	
Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)	Round no.	Average velocity (ft/s)
4	1200[a]	3	1266[a]	5	1258[a]	3	1318
5	1268[a]	6	1250[a]	7	1248[a]	4	1242
7	1232[a]	8	1261[a]	10	1245[a]	6	1290
11	1215[a]	9	1215[a]	15	1227[a]	8	1242
12	1210[a]	10	1258[a]	20	1178[a]	9	1232[a]
						12	1261[a]
						13	1266
						14	1235[a]
						16	1245
						17	1224[a]
						18	1198[a]
						19	1192[a]

[a]Used to calculate V_{50} ballistic limit.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A sample of 24 ballistic resistant undergarments (soft body armor) from a production lot of 1500 originally distributed to 15 police departments throughout the United States in 1975 for issue to officers as part of a Law Enforcement Assistance Administration demonstration project, was tested for V_{50} ballistic limit. The program was a joint effort of the U.S. Department of Justice National Institute of Justice and the National Research Council of Canada Public Safety Project Office. Tests of ballistic limit were conducted on virgin armor that were never issued, and armor showing evidence of light, moderate, and heavy wear both dry and while wet. The results show that armor does not lose ballistic efficiency as a consequence of age.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

ballistic limit; ballistic-resistant body armor; ballistic testing; body armor; Kevlar; soft body armor

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